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DESIGN and MAGNETIC MEASUREMENTS of the NEW MAGNETS for the SACLAY PROTON SYNCHROTRON

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Summary

The design of the dipoles and quadrupoles for the magnetic circuit of the SATURNE II new synchrotron has been theoretically studied with bidimensionnal programs Magnet and Poisson.

The main features of these magnets are, a large aperture, a short length, a high cycling rate, and curved dipoles (made from elementary glued blocks).

The magnetic measurements are made by punctual and integral coils, which enable one to verify the quality of the magnets and also to adjust the geometry of the end of the poles of the quadrupoles.

I. Introduction -

Within the renovation process of the Saturne proton synchrotron at Saclay, the whole magnetic circuit is being rebuilt. The new machine (SATURNE II) will be of a strong focusing type, with separated function. Its magnetic structure is made up of 16 bending magnets, and 24 quadrupolar lenses.

Most of the characteristics of the former machine remain the same i.e 20 MeV injection energy, 3 GeV top energy, main power supply, site and buildings. The main purpose is to achieve an increased number of particles ($\simeq 2.10^{12}$ pps) within smaller emittances, for nuclear physics needs (ref. 1).

Such small injection energy necessitated the design of large aperture magnets. Since the same power supply is used, dipoles and quadrupoles are connected in serie ; but in order to adjust the working point, two small auxiliary power supplies have been added in derivation for the focusing and defocusing quadrupoles.

In order to insure a good quality of the magnetic characteristics of the magnets and to minimise the effects of tracking - with respect to the high magnetic induction level - we have choosen profiled end faces and coils in the median plane and between the pole faces.

II. Dipoles -

II.1. - general design -

The main characteristics are summarized as follows :

magnetic induction		$0.1 < B_0 < 1.96$ Tesla
usefull area	(horizontal	$\pm$ 0.08 m
	(vertical	$\pm$ 0.06 m
gap width		h = 0.140 m
iron length		L_i = 2.471 m
magnetic length		L_m = 2.489 m
magnetic radius		R_m = 6.3381 m
maximum current		I = 4500 A
rising of the field(max)		$\frac{dB}{dt}$ = 4.2 Ts^{-1}
dipolar tolerance		$<\frac{\Delta B}{B}> = 4.10^{-4}$
hexapolar tolerance (at 8 cm)		$<\frac{\Delta B}{B}> = 10^{-4}$

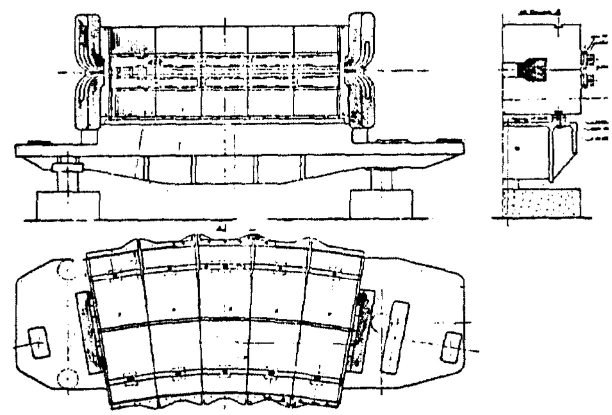

Fig. 1

We have choosen an H type structure for the magnetic circuit, and a part of the current of the coil is between the pole faces, this configuration gives a smaller saturation effect. The different views of the magnet are represented in figure n° 1.

Because of the small magnetic bending radius of the machine and in order to reduce the size of the magnets and also to avoid the angles at the end of the magnets we have designed a curved coil and a magnetic circuit made out of elementary glued blocks, machined on their lateral faces and mechanically assembled with bolts.

All these technological parameters have been long to decide because of the fabrication difficulties they involve. However from a magnetic point of view, and maximum size acceptable for the magnets this design has been retained.

For the fabrication of the blocks we use low decarburised steel sheets, 1.5 mm in thickness and to reduce the coercive force spread between dipoles all the production of steel has been shuffled. Thus we obtain a mean value of 0.545 oersted with a dispersion of ± 0.025 oersted.

For the gluing of the sheets in the blocks we use an epoxy resin, charged with quartz powder. In the fabrication of the coils, the ground mass insulation has been done with mica-glass ribbons.

With respect to the mechanical tolerances, the reference surfaces of the block have been achieved within - 0 + 0.06 mm on the sitting faces and ± 0.03 mm on the pole faces ; and for the coils the positions of the inner conductors are kept within ± 1 mm. The leakage current on the ground mass insulation measured under wet condition is less than 1.10^{-6} A under 11 kV.

II.2. Magnetic characteristics -

The theoretical magnetic characteristics have been studied with a two-dimensionnal model by use of Magnet and Poisson programs. The optimization of the end field, and the design of the end pole faces have been done by two dimensionnal calculations in the plan of symmetry of the magnet.

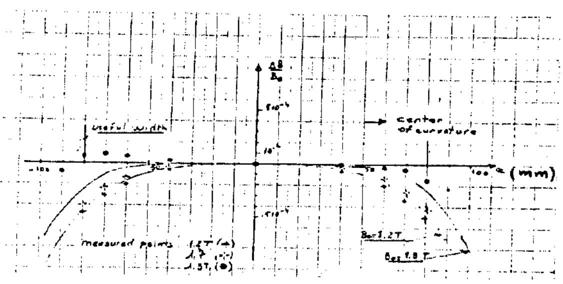

Fig. 2

The punctual magnetic measurements (ref. 2) are in good agreement with the calculations done in the central section, until 1.7 Tesla (see fig. n° 2). The stray fields of the end faces agree within 1 % with the calculated estimations. The azimuthal variations of the radial field map have been measured, and we have found the influence of the machining of the lateral faces of the blocks which cut the sheets so that we change from an H type magnet to a C type one at the junction of two adjacent blocks. The maximum amplitude of these azimuthal variations of the field is less than 5.10^{-4}.

With respect to the integral characteristics of the magnetic field directly measured (or calculated from punctual measurements) we have found a compensation of azimuthal defects. The radial variation of the magnetic length is represented in fig. n° 3.

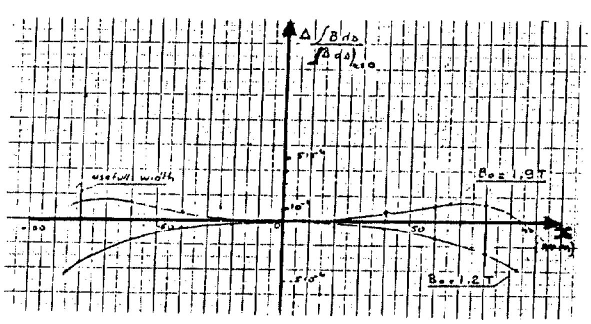

Fig. 3

The shimming of the end faces needs only a dipolar adjustment of about 2 mm in thickness.

The effects of eddy currents and remanent field at injection have only a dipolar contribution which is inside of the tolerances.

III. Quadrupoles -

III.1. - general design -

Their main characteristics are as follow :

gradient	$0.5\ Tm^{-1} < G_o < 10.56\ Tm^{-1}$	
aperture		Ø 0.192 m
usefull aperture		Ø 0.165 m
iron length	$Q_{(F)}$:	0.458 m
	$Q_{(D)}$:	0.477 m
magnetic length		
	$Q_{(F)}$:	0.4672 m
	$Q_{(D)}$:	0.4863 m
maximum current	:	5000 Ampères
rising time at G_{max}	:	0.5 s
quadrupolar tolerance	$<\frac{\Delta G}{G}>$:	1.10^{-3}

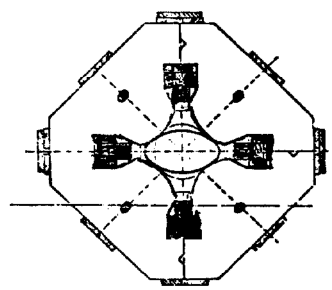

Fig. 4

We have choosen symmetrical type quadrupole (fig. n° 4) with coils in the median plan. The assembling of sheets and poles together is done by welding.

The magnetic calculations of the cross section in the central part have been done with the Magnet program, and we have adjusted the saturation curve as close as possible to that of the dipole by adjusting the position of the central hole behind the pole face.

The shape of the pole end faces of the prototype has been roughly extrapolated from the shape of a similar quadrupole used on the experimental area. (Final adjustment from measuring)

The mechanical tolerances obtained, on the referenced surfaces are within ± 0.05 mm and ± 0.1 mm on the end faces.

III.2. magnetic characteristics -

The measurement of the magnetic characteristics of the quadrupoles are done with punctual coils and integral coils.

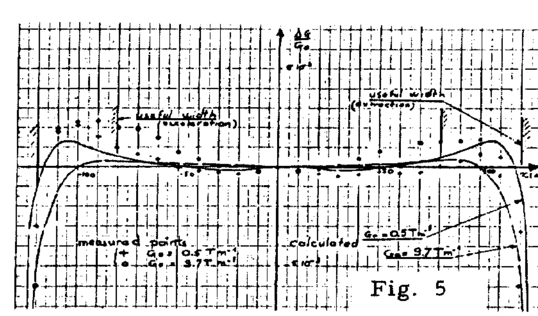

Fig. 5

The magnetic field measured at the center of the quadrupole is in good agreement (ref. 2) with the calculations (fig. n° 5) at every level of the field.

The accurate optimization of the shims on the end face was done with the integral measurements as well as chamfering of the corner of the profile localised on the end face. With such an optimization we have obtained an enlargement of the usefull aperture up to ± 0.120 m within an accuracy (integral) of $\pm 10^{-3}$ (figure n° 6). In fact we need only $\pm 10^{-2}$ for extraction of the beam within ± 0.120 m.

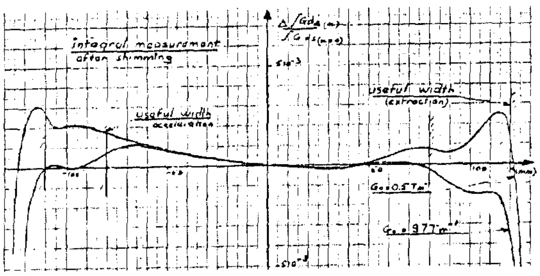

Fig. 6

The saturation characteristics agrees with that of the dipole within 2.10^{-3}.

The eddy currents effects at injection are only quadrupolar and stand within 5.10^{-3}. For saturation and eddy currents defects on the tracking between dipoles and quadrupoles, we had assumed a non-linearity of ± 1 %, so our experimental results are better.

Conclusion -

Although the types of dipoles and quadrupoles are not easy to define and realize. We have obtained for the prototypes and first elements of the serie quite a full range of good results. Thanks to the quality of realization as well as the quality and flexibility of the measurement devices.

References -

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